GEODETIC MEASUREMENT TECHNIQUES FOR 3D SURVEYING OF SURFACES AND BUILT STRUCTURES - INSTRUMENTAL CALIBRATION

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ABSTRACT

In the 3D geodetic survey of surfaces and built structures, the terrestrial measurement instruments typically used are digital levels and total stations. Before collecting field data, particularly for projects aiming at precise results, it is essential to ensure that the measuring instruments are inspected, adjusted, if necessary, classified, and calibrated procedures that are crucial for guaranteeing the accuracy of field measurements. Thus, to ensure the accuracy of the instrument used before field operations began, the Kukkamaeki method was applied to check collimation error, and both the simplified and complete methods of ISO standard 17123-2 (2001) were used to assess the precision of the digital level. It was not necessary to adjust the digital level since both the collimation error value (c) and the equipment's precision were within the specifications required by the methods and standards. Similarly, the horizontal and vertical circles of the total station were verified using the direction method with the AstGeoTop software, and the angular uncertainty achieved complied with NBR 13133 (2021), classified as average angular precision. For future work, it is recommended to automate the robotic total station for prism search and collimation at the observed points.

KEYWORDS: *Instrumental calibration. 3D Surface Survey. Geodetic Survey. Altimetric Control. Settlement Measurements.*

I. INTRODUCTION

According to Filipiak-Kowszyk et al. [1] and Cardoso [2], the phenomenon of displacement in structures within engineering is common and of great interest due to the associated risks. Beyond built structures, there are also situations where large areas are susceptible to 3D movement.

A current example is the subsidence and horizontal displacement process that has been occurring and monitored since 2019 in the neighborhoods of Pinheiro, Mutange, Bebedouro, Bom Parto, and Farol, located in the municipality of Maceió, State of Alagoas. This region features a critical zone of soil subsidence and a surface brittle deformation zone presenting cracks, fissures, fractures, and differential settlement in buildings, houses, and public roads. These neighborhoods are situated among geological fault zones; however, according to the Geological Survey of Brazil [3], anthropogenic mining activities associated with rock salt extraction played a predominant role in triggering the phenomena causing damage in the region.

Structural and surface monitoring can foresee the occurrence of displacements that may directly affect the structures. This process is a preventive measure that can safeguard human lives, avoid environmental disasters, and reduce economic losses. According to Rhadameck [4], geodetic measurement techniques are used to monitor the magnitude and rate of horizontal and vertical deformations in structures and terrain. These techniques are traditionally applied to determine the displacements of surface points of an object relative to stable reference points.

Faggion [5] states that in any field data collection work, especially those aiming for precision results, it is essential to inspect, adjust, if necessary, classify, and calibrate measurement instruments to achieve the required accuracy. In this context, this article aims to address the quality control of instrumentation used in geodetic monitoring, specifically focusing on the Digital Level and Total Station.

The article is structured into five main sections. Section II presents the theoretical framework on data quality control, focusing on the verification of terrestrial surveying instruments. Section III describes the research methodology, covering the study area, the materials used, and the methods applied. Section IV presents and discusses the results of the verifications conducted on the terrestrial surveying instruments. Finally, Section V summarizes the conclusions, recommendations, and contributions of the study.

II. THEORETICAL REFERENCE

According to Camargo [6], quality control in Geodetic Sciences is broad and complex, as it aims to establish, improve and ensure the quality of a product or service for certain conditions of consumption or use. Considering the following factors: economy, time and reliability. In this context, the Kukkamaeki method, the simplified and complete method of the ISO 17123-2 Standard [7] for the use of the digital level and the method of directions to obtain the horizontal direction and vertex angle of a total station will be presented in this work.

2.1. Kukkamaeki Method

The Kukkamaeki method is indicated to evaluate and correct, when necessary, the level collimation error that occurs when the level collimation line is not exactly horizontal. According to Kahmen and Faig [8], the test consists of two stations (I and II), where station I is located 10m from both sights (aft and forward), the method of equal sights, and the reading is carried out. These will contain collimation error (c) vertical of the equal level, because they are at equal distances; soon after, station II is installed 40m from A and 20m from station B, and the reading is carried out, with extreme views. In this case, the readings obtained will contain errors proportional to the distance of the sight, thus the reading a_2 will be equivalent to 4c and reading b_2 to 2c (Figure 1). With this, you can determine the value of the collimation error (c) using equations (1) to (5). Equation (4) is the result of the combination of Equations (1) and (2) in terms of Equation (3). Finally, the value of the error (c) is given by equation (5).

$$a_2 = \Delta h_{AB} + b_2 + 2c \qquad \text{Eq. (1)}$$
$$a_1 = \Delta h_{AB} + b_1 \qquad \text{Eq. (2)}$$
$$\Delta h_{AB} = a_1 - b_1 \qquad \text{Eq. (3)}$$
$$a_2 = a_1 - b_1 + b_2 + 2c \qquad \text{Eq. (4)}$$
$$2c = (a_2 - b_2) - (a_1 - b_1) \ ou \ 2c = \Delta h_{AB-II} - \Delta h_{AB-I} \qquad \text{Eq. (5)}$$

The reticle wires must be moved so that the readings are in accordance with equations (6) and (7) and after final checking, the values obtained must be in accordance with equation (8).

$$a'_1 = a_2 - 4c \qquad \text{Eq. (6)}$$
$$b'_2 = b_2 - 2c \qquad \text{Eq. (7)}$$
$$a_1 - b_1 = a'_2 - b'_2 = \Delta h_{AB} \qquad \text{Eq. (8)}$$

Where c = vertical collimation error; Δh_{AB}= difference in level between points A and B; a_1 = Reading taken from the crosshair positioned at the point A, station I; a_2 = reading taken on the crosshair positioned at point A, Station II; b_1 = reading taken on the crosshair positioned at point B, Station I; b_2 = reading taken on the crosshair positioned at point B, Station II. a'_1= reading that theoretically would have to be observed at point A, without the influence of the collimation error of the level, Station I; b'_1 = a reading that theoretically would have to be observed at point B, without the influence of the collimation error of the level, Station I. The schematization of the method can be seen in Figure 1.

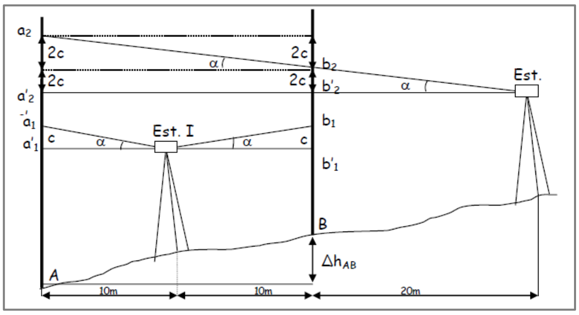

Figure 1. Representation of the Kukkamaeki Method [8].

2.2. Simplified and complete ISO 17123-2 (2001) method

The *International Organization for Standardization* (ISO) is a worldwide body that establishes certification standards for various activities to ensure that products, services and systems are safe, efficient and of quality, promoting global standardization. The ISO standard number 17123-2 [7] specifies the field procedures to be adopted for the evaluation and determination of the accuracy of levels and auxiliary equipment used in topographic and geodetic surveys. The standard describes a simplified procedure and a complete one for the equipment to have its accuracy measured. Details about the application of the simplified and complete method in the field can be seen in ISO 17123-2 [7], Silva [9] and Silva et al. [10].

2.3. Directions Method

According to Espartel [11], by performing the planialtimetric topographic survey by the method of directions and reiterations with a series of conjugated observations of direct position (PD) and inverse position (PI) it is possible to verify the horizontal and vertical limb of the total station to be used in field operations. NBR 13133 [12] defines the direction method as a topographic survey method that consists of horizontal angular measurements with views of the determining directions in the two measurement positions (PD and PI), from a direction taken as the origin. Observations from one direction, in the forward and inverse positions, are called conjugate readings. The interval, measured in the horizontal limb, between the positions of the origin-direction in this limbus, is called the reiteration interval. Thus, for the observation of "n" series of readings conjugated by the direction method, the reiteration interval must be 180°/n. The values of the angles measured by the method of directions are the arithmetic means of their values obtained in the various series.

III. METHODOLOGY

3.1. Study area

The place chosen for the development of this work was the Joaquim Amazonas Campus, in Recife, of the Federal University of Pernambuco (UFPE) (Figure 2).

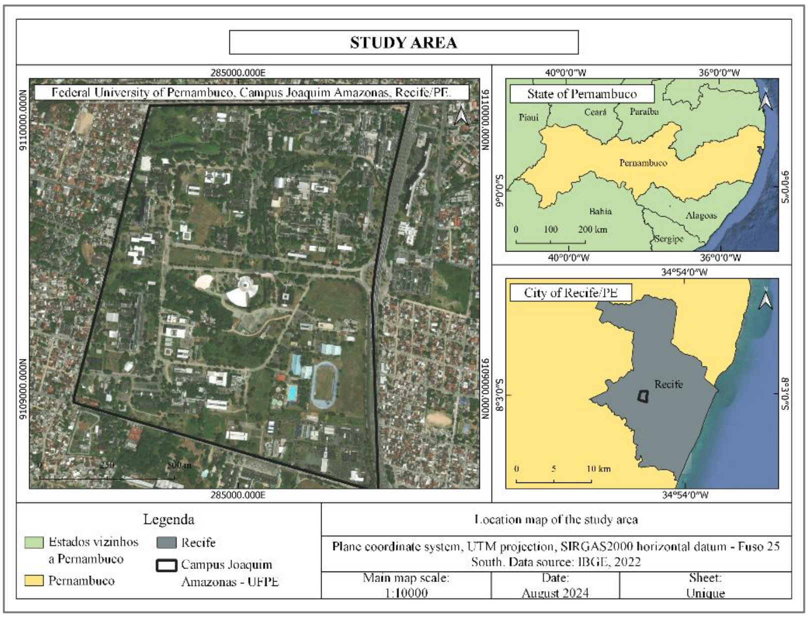

Figure 2. Area of study - Joaquim Amazonas Campus – UFPE [14].

Figure 3 shows the spatial distribution of the geodetic structures of the Joaquim Amazonas Campus of UFPE, used in the instrumental calibration procedures. The points RNA, RNB, RNC and RND are a set of points materialized with pins of semi-spherical surfaces every 20 m that make up the basis for calibration and rectification of levels, presented in Silva [9].

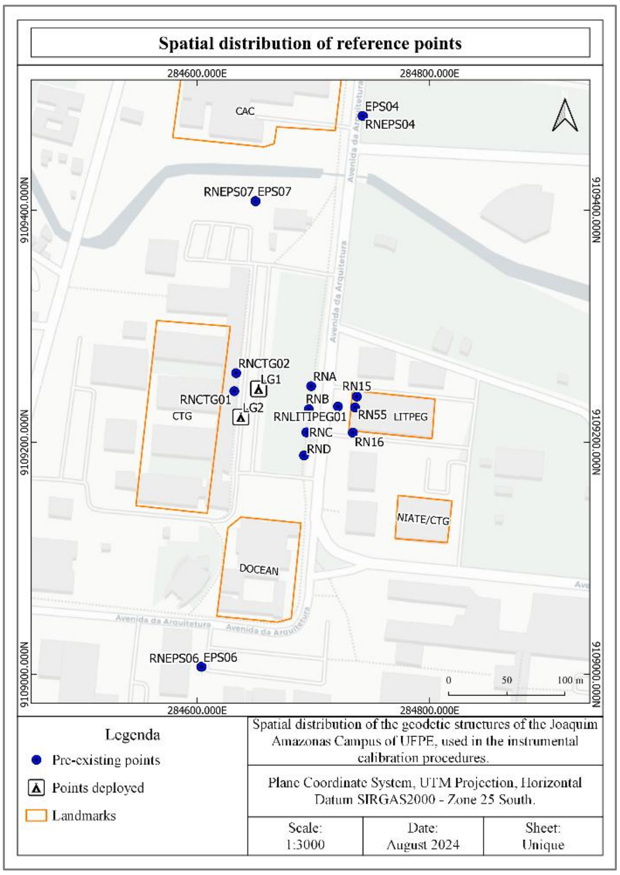

Figure 3. Spatial distribution of station points and object points used in instrumental calibration procedures [14].

3.2. Material and Methods

The equipment verified was the Leica Digital Level, model DNA-03, accuracy of 0.3 mm/Km per double level kilometer and the Trimble Total Station, model M3, with angular accuracy of ±2" and linear precision of 2mm + 2 ppm (parts per million). The accessories used were a 2m barcode invar sight from Leica and a circular prism from Geodetic + sticks. The software used were AstGeoTop [13] and Excel.

IV. RESULTS AND DISCUSSIONS

4.1. Collimation error and digital level accuracy check

The collimation error check of the Leica DNA 03 level was performed using the Kukkamaeki method and then the accuracy check specified by the manufacturer using the Simplified and Complete Methods according to ISO 17123-2 [7]. Both procedures were performed on the same day, September 30, 2021, using the RNA, RNA, RNC, and RND points of the precision verification and level rectification basis (Figure 4).

Figure 4. Application of Kukkamaeki simplified and complete methods of ISO 17123-2 [7]. (a) Measurement of the Level RN_D Reference, (b) Digital level installed in Station 2 of the simplified method, (c) Digital level and adapter tripod for performing the series of readings and (d) Sight installed in the RN_D [14].

The collimation error (c) calculated was -0.00006m (Table 1), which is within the specifications required by the method according to Eq.5 presented in sub-item 2.1, and there is no need to rectify it because it is in accordance with the Eq.8 test.

Table 1. Kukkamaeki Method calculation spreadsheet [14].

Point	Backsight (m)	Foresight (m)	Distance (m)	Level difference (m)	2c (m)	c (m)	Verification		
							a'_2	b'_2	Δh_{AB}
a1	1,44643		9,97	-0,01582	-0,00012	-0,00006	1,4647	1,44888	-0,01582
b1		1,46225	9,97						
a2	1,46446		19,97	-0,01570					
b2		1,44876	39,98						

In the simplified method, the difference between the arithmetic means of the two sets of 10 measurements was calculated (Table 2). Next, it was verified whether the modulus of this difference was less than 2.5 (95% confidence statistic of the results obtained) times the empirical S standard deviation, according to Equation (9).

$$|\overline{D_1} - \overline{D_2}| < 2{,}5 \times S \quad \text{Eq. (9)}$$

Table 2. Field notebook of the 2 sets of 10 observations each, totaling 20 observations [14].

Series	Backsight A (m)	Foresight B (m)	Distance to A (m)	Distance to B (m)	ΔH (A-B) (m)	Residue (m)	Residue² (m²)
1	1,29739	1,31261	29,98	29,96	-0,01522	0,00005	0,0000000
2	1,30385	1,31900	29,98	29,97	-0,01515	-0,00002	0,0000000
3	1,30937	1,32448	29,97	29,97	-0,01511	-0,00006	0,0000000
4	1,31739	1,33263	29,97	29,96	-0,01524	0,00007	0,0000000
5	1,33275	1,34786	29,97	29,96	-0,01511	-0,00006	0,0000000
6	1,36008	1,37531	29,97	29,96	-0,01523	0,00006	0,0000000
7	1,37428	1,38964	29,96	29,96	-0,01536	0,00019	0,0000000
8	1,38386	1,39879	29,97	29,96	-0,01493	-0,00024	0,0000001
9	1,39953	1,41477	29,97	29,96	-0,01524	0,00007	0,0000000
10	1,41579	1,43089	29,98	29,94	-0,01510	-0,00007	0,0000000
11	1,31181	1,32708	9,97	49,97	-0,01527	-0,00008	0,0000000
12	1,32995	1,34532	9,95	49,98	-0,01537	0,00002	0,0000000
13	1,33814	1,35375	9,95	50,01	-0,01561	0,00026	0,0000001
14	1,34843	1,36388	9,95	49,97	-0,01545	0,00010	0,0000000
15	1,36112	1,37650	9,95	49,98	-0,01538	0,00003	0,0000000
16	1,37491	1,39030	9,97	49,97	-0,01539	0,00004	0,0000000
17	1,38451	1,39969	9,97	49,98	-0,01518	-0,00017	0,0000000
18	1,39779	1,41296	9,96	49,98	-0,01517	-0,00018	0,0000000
19	1,41031	1,42572	9,97	49,96	-0,01541	0,00006	0,0000000
20	1,42031	1,43561	9,96	49,97	-0,01530	-0,00005	0,0000000

Table 3 presents the results obtained in the verification of the accuracy of the digital level, according to the ISO 17123-2 standard [7], using the simple method. The difference ($\overline{D_1} - \overline{D_2}$) obtained was 0.184 mm, with one standard deviation S = ±0,116 mm and the statistical test was 0.29 mm. Therefore, according to the test $|\overline{D_1} - \overline{D_2}| < 2{,}5 \times S$ (Eq.9), the measures are within the acceptable limit and considered approved.

Table 3. Analysis of the digital level check using the simplified method of ISO 17123-2 [7] e [14].

Observations	Arithmetic means of observations (mm)	Standard deviation (S) (mm)	Statistics of 95% (mm)	Status
$\overline{D_1}$	-15,169	±0,116	0,29	Approved
$\overline{D_2}$	-15,353			
$\overline{D_1} - \overline{D_2}$	0,184			

In the complete method, the difference between the arithmetic means of the two sets of 20 measurements is calculated (Table 4). It is then checked whether the module of this difference $|\overline{D_1} - \overline{D_2}|$ is less than 2.89 times the standard deviation S considering 95% confidence for the results obtained, according to Equation (10).

$$|\overline{D_1} - \overline{D_2}| < 2{,}89 \times S \qquad \text{Eq. (10)}$$

Table 4. Field notebook of the 2 sets of 20 observations, totaling 40 observations [14].

Series	Backsight A (m)	Foresight B (m)	Distance to A (m)	Distance to B (m)	ΔH (A-B) (m)	Residue (m)	Residue² (m²)
1	1,29739	1,31261	29,98	29,96	-0,01522	0,00001	0,0000000
2	1,30385	1,31900	29,98	29,97	-0,01515	-0,00006	0,0000000
3	1,30937	1,32448	29,97	29,97	-0,01511	-0,00010	0,0000000
4	1,31739	1,33263	29,97	29,96	-0,01524	0,00003	0,0000000
5	1,33275	1,34786	29,97	29,96	-0,01511	-0,00010	0,0000000
6	1,36008	1,37531	29,97	29,96	-0,01523	0,00002	0,0000000
7	1,37428	1,38964	29,96	29,96	-0,01536	0,00015	0,0000000
8	1,38386	1,39879	29,97	29,96	-0,01493	-0,00028	0,0000001
9	1,39953	1,41477	29,97	29,96	-0,01524	0,00003	0,0000000

10	1,41579	1,43089	29,98	29,94	-0,01510	-0,00011	0,0000000
11	1,32107	1,33634	29,97	29,96	-0,01527	0,00006	0,0000000
12	1,32850	1,34356	29,96	29,95	-0,01506	-0,00015	0,0000000
13	1,33697	1,35228	29,96	29,97	-0,01531	0,00010	0,0000000
14	1,34692	1,36216	29,98	29,95	-0,01524	0,00003	0,0000000
15	1,35392	1,36935	29,97	29,97	-0,01543	0,00022	0,0000000
16	1,36297	1,37829	29,97	29,96	-0,01532	0,00011	0,0000000
17	1,37345	1,38869	29,98	29,97	-0,01524	0,00003	0,0000000
18	1,38170	1,39697	29,98	29,98	-0,01527	0,00006	0,0000000
19	1,39074	1,40595	29,98	29,98	-0,01521	0,00000	0,0000000
20	1,40202	1,41718	29,97	29,98	-0,01516	-0,00005	0,0000000
21	1,42687	1,44213	29,98	29,97	-0,01526	0,00001	0,0000000
22	1,43893	1,45403	29,98	29,96	-0,01510	-0,00015	0,0000000
23	1,44636	1,46160	29,98	29,96	-0,01524	-0,00001	0,0000000
24	1,45437	1,46963	29,98	29,97	-0,01526	0,00001	0,0000000
25	1,44511	1,46023	29,99	29,97	-0,01512	-0,00013	0,0000000
26	1,43608	1,45126	29,98	29,97	-0,01518	-0,00007	0,0000000
27	1,42892	1,44423	29,98	29,97	-0,01531	0,00006	0,0000000
28	1,42230	1,43759	29,98	29,97	-0,01529	0,00004	0,0000000
29	1,41225	1,42750	29,99	29,98	-0,01525	0,00000	0,0000000
30	1,40167	1,41695	29,98	29,97	-0,01528	0,00003	0,0000000
31	1,32130	1,33660	29,99	29,97	-0,01530	0,00005	0,0000000
32	1,33759	1,35289	29,98	29,97	-0,01530	0,00005	0,0000000
33	1,35144	1,36682	29,99	29,97	-0,01538	0,00013	0,0000000
34	1,36980	1,38506	29,98	29,98	-0,01526	0,00001	0,0000000
35	1,38639	1,40164	29,98	29,97	-0,01525	0,00000	0,0000000
36	1,40776	1,42302	29,97	29,98	-0,01526	0,00001	0,0000000
37	1,42194	1,43723	29,97	29,97	-0,01529	0,00004	0,0000000
38	1,44573	1,46094	29,98	29,96	-0,01521	-0,00004	0,0000000
39	1,40406	1,41924	29,99	29,98	-0,01518	-0,00007	0,0000000
40	1,42360	1,43893	29,98	29,98	-0,01533	0,00008	0,0000000

Table 5 presents the results obtained in the calibration of the digital level, according to the standard ISO 17123-2 [7], using the complete method. The difference ($\overline{D_1} - \overline{D_2}$) obtained was 0.042 mm. Therefore, according to the test $|\overline{D_1} - \overline{D_2}| < 2,89 \times S$ (Eq.10), with a value of 0.269 mm, the measurements are within the acceptable limit and considered approved.

Table 5. Analysis of the digital level check using the complete ISO 17123-2 (2001) method [14].

Observations	**Arithmetic means of observations (mm)**	**Standard deviation (S) (mm)**	**Statistics of 95% (mm)**	**Status**
$\overline{D_1}$	-15,210	±0,093	0,269	Approved
$\overline{D_2}$	-15,252			
$\overline{D_1} - \overline{D_2}$	0,042			

The standard deviation, informed by the manufacturer, of the equipment used is ± 0.3 mm/Km. This value multiplied by the constant of 1.19 indicated in question (a) of the ISO 17123-2 standard [7] results in ± 0.357 mm, which is greater than the standard deviation S found in Table 5, with a value ± 0.093 mm. Therefore, the observations satisfied the statistical test indicated in the standard.

4.2.Checking the accuracy of the horizontal and vertical limb of the total station

The procedure to verify the accuracy of the horizontal and vertical limb of the total station was carried out from the implanted geodetic structure composed of points LG1 and LG2 (Figure 5), used as station points, and observations radiated to the pre-existing points in the study area using the method of directions with series of conjugated observations in forward and reverse position, changing the origin so that there are readings distributed throughout the horizontal limb.

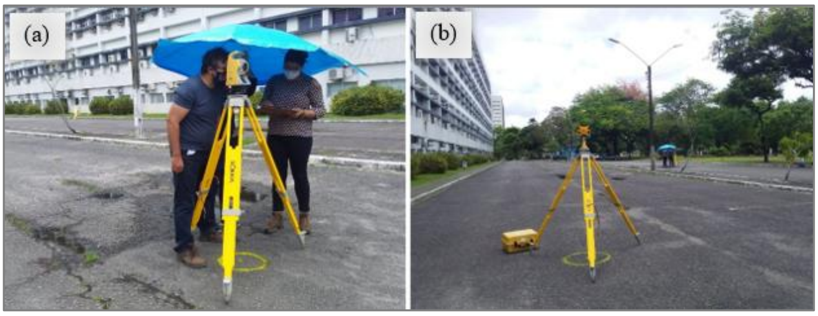

Figure 5. Procedure for the implementation of the LG1 and LG2 vertices. (a) Total Station parked at vertex LG1 and (b) Prism centered at vertex LG2 [14].

Table 6 shows the field notebook with the data collected from the LG1 station point and the measurements of 17 targets with 2 series were made.

Table 6. Field Notebook - LG1 Station with 2 sets of 17 targets each [14].

Directions Method – LG1 Station						
Series	**Target point**	**Horizontal Angle (PD)**	**Zenith Angle (PD)**	**Horizontal Angle (PI)**	**Zenith Angle (PI)**
1	EPS07	0°00`00,0"	90°12`58,0"	179°59`54,0"	269°45`40,0"
	RNEPS07	0°02`21,0"	89°59`47,0"	180°02`10,0"	269°58`55,0"
	RNEPS04	21°47`46,0"	89°54`25,0"	201°47`32,0"	270°04`09,0"
	EPS04	21°51`41,0"	90°04`05,0"	201°51`29,0"	269°54`25,0"
	RNA_P	87°59`13,0"	89°33`53,0"	267°59`00,0"	270°24`39,0"
	RN15_A	95°29`07,0"	90°47`33,0"	275°28`59,0"	269°11`02,0"
	RN15_P	95°34`17,0"	89°19`43,0"	275°34`03,0"	270°38`43,0"
	RNLITPEG01	103°33`03,0"	90°09`04,0"	283°32`54,0"	269°49`27,0"
	RNB_P	113°07`27,0"	89°35`47,0"	293°07`21,0"	270°22`43,0"
	RN16_P	115°52`29,0"	89°21`20,0"	295°53`29,0"	270°37`01,0"
	RN16_A	115°56`36,0"	90°44`42,0"	295°56`25,0"	269°13`51,0"
	RNC_P	133°20`42,0"	89°38`57,0"	313°20`26,0"	270°19`29,0"
	RND_P	146°44`45,0"	89°43`24,0"	326°44`42,0"	270°15`03,0"
	EPS06	192°36`50,0"	90°09`07,0"	12°36`37,0"	269°49`34,0"
	LG2	213°06`06,0"	89°51`03,0"	33°05`55,0"	270°07`26,0"
	RNCTG01	265°28`23,0"	87°20`43,0"	85°28`06,0"	272°37`44,0"
	RNCTG02	305°55`31,0"	87°33`14,0"	125°55`06,0"	272°25`27,0"
2	EPS07	359°59`59,0"	90°12`50,0"	179°59`54,0"	269°45`39,0"
	RNEPS07	0°02`23,0"	89°59`59,0"	180°02`12,0"	269°58`48,0"
	RNEPS04	21°47`48,0"	89°54`25,0"	201°47`31,0"	270°04`08,0"
	EPS04	21°51`44,0"	90°04`01,0"	201°51`32,0"	269°54`29,0"
	RNA_P	87°59`29,0"	89°33`50,0"	267°59`19,0"	270°24`38,0"
	RN15_A	95°29`08,0"	90°47`35,0"	275°28`57,0"	269°10`52,0"
	RN15_P	95°34`21,0"	89°19`43,0"	275°34`08,0"	270°38`47,0"
	RNLITPEG01	103°33`05,0"	90°09`06,0"	283°32`58,0"	269°49`22,0"
	RNB_P	113°07`33,0"	89°35`43,0"	293°07`22,0"	270°22`45,0"
	RN16_P	115°52`40,0"	89°21`23,0"	295°53`02,0"	270°37`02,0"
	RN16_A	115°56`35,0"	90°44`40,0"	295°56`23,0"	269°13`52,0"
	RNC_P	133°20`34,0"	89°38`59,0"	313°20`26,0"	270°19`31,0"
	RND_P	146°44`50,0"	89°43`27,0"	326°44`44,0"	270°15`00,0"
	EPS06	192°36`50,0"	90°09`02,0"	12°36`37,0"	269°49`33,0"
	LG2	213°06`10,0"	89°51`04,0"	33°06`03,0"	270°07`28,0"
	RNCTG01	265°29`02,0"	87°20`32,0"	85°28`19,0"	272°37`56,0"
	RNCTG02	305°55`20,0"	87°33`04,0"	125°55`07,0"	272°25`27,0"

Figure 6 shows the scheme of the directions method with the total station positioned at the LG1 vertex and the 17 observations made (EPS04, EPS06, EPS07, RNEPS04, RNEPS07, LG2, RNCTG01,

RNCTG02, RNA_P, RNB_P, RNC_P, RND_P, RN15_A, RNLITPEG01, RN15_P, RN16_A, RN16_P) (Figure 6).

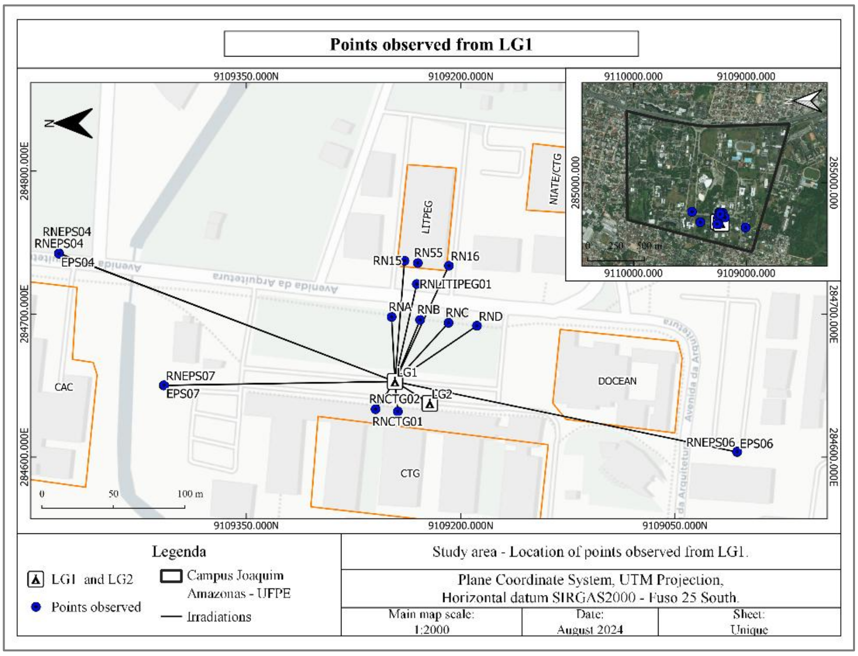

Figure 6. Points observed from LG1 [14].

Table 7 shows the field notebook with the data collected from the LG2 station point and the measurements of 20 targets with 2 sets were made.

Table 7. Field Notebook - LG2 station with 2 sets of 20 targets each [14].

Directions Method - LG2 Station					
Series	**Target point**	**Horizontal Angle (PD)**	**Zenith Angle (PD)**	**Horizontal Angle (PI)**	**Zenith Angle (PI)**
1	EPS07	359°59`55,0"	90°10`50,0"	179°59`52,0"	269°47`44,0"
	RNEPS07	0°02`15,0"	89°58`02,0"	180°02`07,0"	270°00`30,0"
	RNEPS04	18°07`07,0"	89°54`40,0"	198°06`59,0"	270°03`55,0"
	EPS04	18°10`41,0"	90°03`24,0"	198°10`28,0"	269°55`01,0"
	LG1	28°16`24,0"	89°52`31,0"	208°16`24,0"	270°05`59,0"
	RNA_P	62°18`14,0"	89°41`09,0"	242°17`58,0"	270°17`16,0"
	RN15_A	76°04`36,0"	90°39`11,0"	256°04`34,0"	269°19`21,0"
	RN15_P	76°08`23,0"	89°25`47,0"	256°08`24,0"	270°32`41,0"
	RNB_P	79°29`04,0"	89°39`48,0"	259°29`17,0"	270°18`47,0"
	RNLITPEG01	79°53`09,0"	90°06`48,0"	259°53`08,0"	269°51`40,0"
	RN55_A	81°14`20,0"	90°40`52,0"	261°14`31,0"	269°17`34,0"
	RN55_P	81°15`21,0"	89°25`15,0"	261°15`27,0"	270°33`13,0"
	RN16_P	93°58`16,0"	89°23`49,0"	273°58`11,0"	270°34`23,0"
	RN16_A	94°02`11,0"	90°40`34,0"	274°02`13,0"	269°18`07,0"
	RNC_P	99°12`57,0"	89°38`57,0"	279°12`58,0"	270°19`26,0"
	RND_P	117°24`49,0"	89°41`16,0"	297°24`49,0"	270°17`16,0"
	RNEPS06	185°03`20,0"	89°58`35,0"	5°03`13,0"	269°59`44,0"
	EPS06	185°07`35,0"	90°09`57,0"	5°07`36,0"	269°48`20,0"
	RNCTG01	341°56`09,0"	87°32`16,0"	161°56`12,0"	272°26`11,0"
	RNCTG02	350°02`52,0"	89°22`48,0"	170°02`49,0"	270°35`37,0"
2	EPS07	0°00`04,0"	90°10`50,0"	179°59`42,0"	269°47`40,0"
	RNEPS07	0°02`20,0"	89°57`49,0"	180°02`06,0"	270°00`30,0"
	RNEPS04	18°07`13,0"	89°54`35,0"	198°07`04,0"	270°03`53,0"
	EPS04	18°10`39,0"	90°03`28,0"	198°10`31,0"	269°55`02,0"

	LG1	28°16`22,0"	89°52`33,0"	208°16`25,0"	270°06`03,0"
	RNA_P	62°17`58,0"	89°41`11,0"	242°17`50,0"	270°17`20,0"
	RN15_A	76°04`36,0"	90°39`16,0"	256°04`28,0"	269°19`22,0"
	RN15_P	76°08`31,0"	89°25`40,0"	256°08`34,0"	270°32`44,0"
	RNB_P	79°29`04,0"	89°39`43,0"	259°29`07,0"	270°18`43,0"
	RNLITPEG01	79°53`11,0"	90°06`55,0"	259°53`06,0"	269°51`37,0"
	RN55_A	81°14`30,0"	90°40`53,0"	261°14`23,0"	269°17`48,0"
	RN55_P	81°15`29,0"	89°25`12,0"	261°15`25,0"	270°33`16,0"
	RN16_P	93°58`15,0"	89°24`00,0"	273°58`16,0"	270°34`11,0"
	RN16_A	94°02`10,0"	90°40`34,0"	274°02`05,0"	269°18`06,0"
	RNC_P	99°12`52,0"	89°39`00,0"	279°12`57,0"	270°19`31,0"

Figure 7 shows the scheme of the direction method with the total station positioned at the LG2 vertex and from it 20 observations were made (EPS04, EPS06, EPS07, RNEPS04, RNEPS06 RNEPS07, LG1, RNCTG01, RNCTG02, RNA_P, RNB_P, RNC_P, RND_P, RN15_A, RNLITPEG01, RN15_P, RN16_A, RN16_P, RN55_A and RN55_P).

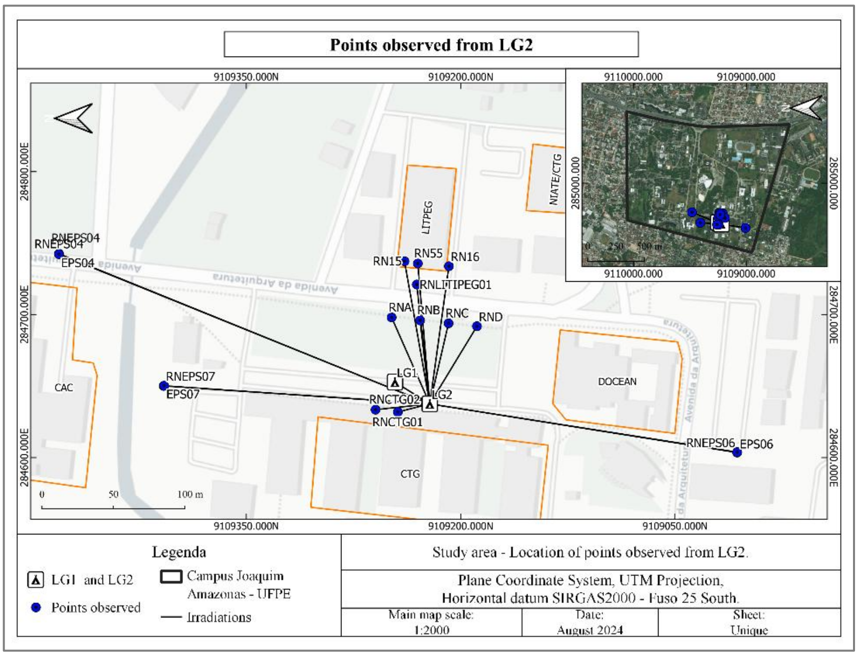

Figure 7. Points observed from LG2 [14].

To obtain the instrumental classification with respect to horizontal and vertical angular precision, the field notebooks with the LG1 and LG2 data were inserted in *the* AstGeoTop software [13] using the Horizontal and Zenithal Angle Calculation Module and the calculation of the averages of the angles in PD and PI was performed. The processing reports and the respective results of the checks performed in the software [13] can be found in Figure 8 and Figure 9.

```
------------------------------------------------------------------------------------
                DISCREPANCIES HORIZONTAL ANGLES AND ZENITAL ANGLES
------------------------------------------------------------------------------------
        HORIZONTAL ANGLE DISCREPANCIES          ZENITAL ANGLE DISCREPANCIES
Series      DMax    Dmin     Daverage  S.dev         DDMax    Dmin    Daverage  S.dev
------------------------------------------------------------------------------------
1           60,00"  -25,00"  -7,59"    18,12"        99,00"   78,00"  88,06"    5,98"
------------------------------------------------------------------------------------
2           22,00"  -43,00"  -10,41"   11,89"        95,00"   73,00"  89,41"    4,91"
====================================================================================
                          JOINT RESULT OF THE 2 SERIES
        HORIZONTAL ANGLE DISCREPANCIES          ZENITAL ANGLE DISCREPANCIES
Series      DMax    Dmin     Daverage  S.dev         DDMax    Dmin    Daverage  S.dev
TODAS       60,00"  -43,00"  -9,00"    15,16"        99,00"   73,00"  88,74"    5,43"
====================================================================================
                        ANGLES ADJUSTED BY LEAST SQUARES
===================================================================================
HORIZONTAL ANGLES ADJUSTED BY MMQ               ZENITAL ANGLES ADJUSTED BY MMQ
x0 =           0°00`00,0"     +/- 0,0"     |    z1 =          90°13`37,3"    +/- 2,4"
x1 =           0°02`19,7"     +/- 5,7"     |    z2 =          90°00`30,8"    +/- 2,4"
x2 =          21°47`42,5"     +/- 5,7"     |    z3 =          89°55`08,2"    +/- 2,4"
x3 =          21°51`39,7"     +/- 5,7"     |    z4 =          90°04`48,0"    +/- 2,4"
x4 =          87°59`18,5"     +/- 5,7"     |    z5 =          89°34`36,5"    +/- 2,4"
x5 =          95°29`06,0"     +/- 5,7"     |    z6 =          90°48`18,5"    +/- 2,4"
x6 =          95°34`15,5"     +/- 5,7"     |    z7 =          89°20`29,0"    +/- 2,4"
x7 =         103°33`03,2"     +/- 5,7"     |    z8 =          90°09`50,2"    +/- 2,4"
x8 =         113°07`29,0"     +/- 5,7"     |    z9 =          89°36`30,5"    +/- 2,4"
x9 =         115°52`58,3"     +/- 5,7"     |    z10 =         89°22`10,0"    +/- 2,4"
x10 =        115°56`33,0"     +/- 5,7"     |    z11 =         90°45`24,8"    +/- 2,4"
x11 =        133°20`35,3"     +/- 5,7"     |    z12 =         89°39`44,0"    +/- 2,4"
x12 =        146°44`48,5"     +/- 5,7"     |    z13 =         89°44`12,0"    +/- 2,4"
x13 =        192°36`46,8"     +/- 5,7"     |    z14 =         90°09`45,5"    +/- 2,4"
x14 =        213°06`06,8"     +/- 5,7"     |    z15 =         89°51`48,3"    +/- 2,4"
x15 =        265°28`30,8"     +/- 5,7"     |    z16 =         87°21`23,8"    +/- 2,4"
x16 =        305°55`19,3"     +/- 5,7"     |    z17 =         87°33`51,0"    +/- 2,4"
ESTIMATED WASTE FROM HORIZONTAL DIRECTIONS    ESTIMATED RESIDUES OF ZENITAL ANGLES
v1 =          -0°00`01,7"                  |    v1 =         -0°00`01,7"
v2 =          -0°00`00,5"                  |    v2 =          0°00`04,8"
v3 =          -0°00`01,2"                  |    v3 =          0°00`00,3"
v4 =           0°00`00,0"                  |    v4 =         -0°00`02,0"
v5 =           0°00`07,3"                  |    v5 =         -0°00`00,5"
v6 =          -0°00`01,7"                  |    v6 =          0°00`03,0"
v7 =           0°00`00,8"                  |    v7 =         -0°00`01,0"
v8 =           0°00`00,0"                  |    v8 =          0°00`01,7"
v9 =           0°00`00,3"                  |    v9 =         -0°00`01,5"
v10 =         -0°00`05,5"                  |    v10 =         0°00`00,5"
v11 =         -0°00`02,2"                  |    v11 =        -0°00`00,7"
v12 =         -0°00`03,5"                  |    v12 =         0°00`00,0"
v13 =          0°00`00,3"                  |    v13 =         0°00`01,5"
v14 =         -0°00`01,5"                  |    v14 =        -0°00`01,0"
v15 =          0°00`01,5"                  |    v15 =        -0°00`00,2"
v16 =          0°00`11,5"                  |    v16 =        -0°00`05,8"
v17 =         -0°00`04,0"                  |    v17 =        -0°00`02,5"
v18 =          0°00`01,7"                  |    v18 =         0°00`01,7"
v19 =          0°00`00,5"                  |    v19 =        -0°00`04,8"
v20 =          0°00`01,2"                  |    v20 =        -0°00`00,3"
v21 =         -0°00`00,0"                  |    v21 =         0°00`02,0"
v22 =         -0°00`07,3"                  |    v22 =         0°00`00,5"
v23 =          0°00`01,7"                  |    v23 =        -0°00`03,0"
v24 =         -0°00`00,8"                  |    v24 =         0°00`01,0"
v25 =         -0°00`00,0"                  |    v25 =        -0°00`01,7"
v26 =         -0°00`00,3"                  |    v26 =         0°00`01,5"
v27 =          0°00`05,5"                  |    v27 =        -0°00`00,5"
v28 =          0°00`02,2"                  |    v28 =         0°00`00,7"
v29 =          0°00`03,5"                  |    v29 =         0°00`00,0"
v30 =         -0°00`00,3"                  |    v30 =        -0°00`01,5"
v31 =          0°00`01,5"                  |    v31 =         0°00`01,0"
v32 =         -0°00`01,5"                  |    v32 =         0°00`00,2"
v33 =         -0°00`11,5"                  |    v33 =         0°00`05,8"
v34 =          0°00`04,0"                  |    v34 =         0°00`02,5"

CLASSIFICATION OF HORIZONTAL ANGULAR ACCURACY    CLASSIFICATION OF VERTICAL ANGULAR ACCURACY
Standard deviation = 5,7"                         Standard deviation = 3,4"
```

Figure 8. Processing report and the results of the checks performed in the software AstGeoTop - Horizontal and Zenithal Angle Calculation Module [13] from LG1 data [14].

```
                 DISCREPANCIES HORIZONTAL ANGLES AND ZENITAL ANGLES
---------------------------------------------------------------------------------------------
         HORIZONTAL ANGLE DISCREPANCIES                ZENITAL ANGLE DISCREPANCIES
Series       DMax     Dmin      Daverage  S.dev          DDMax      Dmin   Daverage  S.dev
---------------------------------------------------------------------------------------------
1           13,00"  -16,00"    -1,40"     7,08"         108,00"   79,00"   92,30"    6,76"
---------------------------------------------------------------------------------------------
2            8,00"  -22,00"    -3,45"     7,30"         109,00"   79,00"   91,30"    7,67"
=============================================================================================
                            JOINT RESULT OF THE 2 SERIES
         HORIZONTAL ANGLE DISCREPANCIES                ZENITAL ANGLE DISCREPANCIES
Series       DMax     Dmin      Daverage  S.dev          DDMax     Dmin   Daverage    S.dev
TODAS       13,00"  -22,00"    -2,43"     7,18"         109,00"   79,00"   91,80"    7,15"
=============================================================================================
                          ANGLES ADJUSTED BY LEAST SQUARES
============================================================================================
HORIZONTAL ANGLES ADJUSTED BY MMQ                   ZENITAL ANGLES ADJUSTED BY MMQ
x0 =             0°00`00,0"     +/- 0,0"      |     z1 =           90°11`34,0"      +/- 2,7"
x1 =             0°02`18,7"     +/- 3,1"      |     z2 =           89°58`42,8"      +/- 2,7"
x2 =            18°07`12,5"     +/- 3,1"      |     z3 =           89°55`21,7"      +/- 2,7"
x3 =            18°10`41,5"     +/- 3,1"      |     z4 =           90°04`12,2"      +/- 2,7"
x4 =            28°16`30,5"     +/- 3,1"      |     z5 =           89°53`15,5"      +/- 2,7"
x5 =            62°18`06,7"     +/- 3,1"      |     z6 =           89°41`56,0"      +/- 2,7"
x6 =            76°04`40,3"     +/- 3,1"      |     z7 =           90°39`56,0"      +/- 2,7"
x7 =            76°08`34,7"     +/- 3,1"      |     z8 =           89°26`30,5"      +/- 2,7"
x8 =            79°29`14,7"     +/- 3,1"      |     z9 =           89°40`30,2"      +/- 2,7"
x9 =            79°53`15,2"     +/- 3,1"      |     z10 =          90°07`36,5"      +/- 2,7"
x10 =           81°14`32,7"     +/- 3,1"      |     z11 =          90°41`35,7"      +/- 2,7"
x11 =           81°15`32,2"     +/- 3,1"      |     z12 =          89°25`59,5"      +/- 2,7"
x12 =           93°58`21,2"     +/- 3,1"      |     z13 =          89°24`48,7"      +/- 2,7"
x13 =           94°02`16,5"     +/- 3,1"      |     z14 =          90°41`13,7"      +/- 2,7"
x14 =           99°13`02,7"     +/- 3,1"      |     z15 =          89°39`45,0"      +/- 2,7"
x15 =          117°24`54,7"     +/- 3,1"      |     z16 =          89°42`00,5"      +/- 2,7"
x16 =          185°03`24,7"     +/- 3,1"      |     z17 =          89°59`24,2"      +/- 2,7"
x17 =          185°07`41,7"     +/- 3,1"      |     z18 =          90°10`41,0"      +/- 2,7"
x18 =          341°56`17,5"     +/- 3,1"      |     z19 =          87°33`03,5"      +/- 2,7"
x19 =          350°02`56,0"     +/- 3,1"      |     z20 =          89°23`34,5"      +/- 2,7"

ESTIMATED WASTE FROM HORIZONTAL DIRECTIONS        ESTIMATED RESIDUES OF ZENITAL ANGLES
v1 =            -0°00`00,1"                   |     v1 =            0°00`01,0"
v2 =             0°00`01,2"                   |     v2 =           -0°00`03,2"
v3 =             0°00`02,9"                   |     v3 =           -0°00`00,8"
v4 =             0°00`00,4"                   |     v4 =            0°00`00,7"
v5 =            -0°00`00,1"                   |     v5 =           -0°00`00,5"
v6 =            -0°00`05,8"                   |     v6 =           -0°00`00,5"
v7 =            -0°00`01,3"                   |     v7 =            0°00`01,0"
v8 =             0°00`04,7"                   |     v8 =           -0°00`02,5"
v9 =            -0°00`02,3"                   |     v9 =           -0°00`00,2"
v10 =            0°00`00,2"                   |     v10 =           0°00`02,5"
v11 =            0°00`00,7"                   |     v11 =          -0°00`03,2"
v12 =            0°00`01,7"                   |     v12 =          -0°00`01,5"
v13 =            0°00`01,2"                   |     v13 =           0°00`05,8"
v14 =           -0°00`02,1"                   |     v14 =           0°00`00,2"
v15 =           -0°00`01,3"                   |     v15 =          -0°00`00,5"
v16 =           -0°00`00,8"                   |     v16 =           0°00`00,5"
v17 =            0°00`01,7"                   |     v17 =          -0°00`01,2"
v18 =           -0°00`00,3"                   |     v18 =          -0°00`07,5"
v19 =            0°00`00,4"                   |     v19 =           0°00`01,0"
v20 =           -0°00`01,1"                   |     v20 =          -0°00`01,0"
v21 =            0°00`00,1"                   |     v21 =          -0°00`01,0"
v22 =           -0°00`01,2"                   |     v22 =           0°00`03,2"
v23 =           -0°00`02,9"                   |     v23 =           0°00`00,8"
v24 =           -0°00`00,4"                   |     v24 =          -0°00`00,7"
v25 =            0°00`00,1"                   |     v25 =           0°00`00,5"
v26 =            0°00`05,8"                   |     v26 =           0°00`00,5"
v27 =            0°00`01,3"                   |     v27 =          -0°00`01,0"
v28 =           -0°00`04,7"                   |     v28 =           0°00`02,5"
v29 =            0°00`02,3"                   |     v29 =           0°00`00,2"
v30 =           -0°00`00,2"                   |     v30 =          -0°00`02,5"
v31 =           -0°00`00,7"                   |     v31 =           0°00`03,2"
v32 =           -0°00`01,7"                   |     v32 =           0°00`01,5"
v33 =           -0°00`01,2"                   |     v33 =          -0°00`05,8"
v34 =            0°00`02,1"                   |     v34 =          -0°00`00,2"
v35 =            0°00`01,3"                   |     v35 =           0°00`00,5"
v36 =            0°00`00,8"                   |     v36 =          -0°00`00,5"
v37 =           -0°00`01,7"                   |     v37 =           0°00`01,2"
v38 =            0°00`00,3"                   |     v38 =           0°00`07,5"
v39 =           -0°00`00,4"                   |     v39 =          -0°00`01,0"
v40 =            0°00`01,1"                   |     v40 =           0°00`01,0"

CLASSIFICATION OF HORIZONTAL ANGULAR ACCURACY       CLASSIFICATION OF VERTICAL ANGULAR ACCURACY
Standard deviation = 3,1"                           Standard deviation = 3,8"
```

Figure 9. Processing report and the results of the checks performed in the software AstGeoTop - Horizontal and Zenithal Angle Calculation Module [13] from LG2 data [14].

The joint calculation of the two series (forward position and inverse position) showed the following standard deviations: With the data from the LG1 station point the discrepancy of the horizontal angles at 15.16" and the horizontal angular accuracy classification of 5.7"; the discrepancy of the vertical angles at 5.43" and the vertical angular accuracy rating of 3.4". While for the data from the LG2 station point the discrepancy of the horizontal angles at 7.18" and the horizontal angular accuracy rating of 3.1"; the discrepancy of vertical angles at 7.15" and vertical angular accuracy rating of 3.8".

In addition to these results, the module presents the horizontal and vertical angles adjusted by the least squares method, as well as the estimated residuals for the horizontal and vertical directions. Likewise, for LG1 the smallest residue in the horizontal directions was -11.5" and the largest was 11.5"; for the vertical angles, the smallest residue was -4.8" and the largest residue was 5.8". While for LG2 the smallest residue in the horizontal directions was -5.8" and the largest residue was 5.8". For the vertical angles, the smallest residue was -7.5" and the largest residue was 7.5". In view of the results presented, the classification of the precision of the total station, based on each station point, is shown in Table 8.

Table 8. Verification of the accuracy of the limbs of the robotic total station [14].

Station Point	Accuracy Rating	
	Horizontal Angle	Vertical Angle
LG1	5,7”	3,4”
LG2	3,1”	3,8”

V. CONCLUSIONS

The result obtained in the verification of the collimation error (c) of the Leica DNA 03 digital level, using the Kukkamaeki method, was -0.00006m. This value is within the specifications required by the method and there was no need to rectify. When performing the verification of the accuracy specified by the manufacturer (0.3 mm/km), the simplified and complete methods described in the ISO 17123-2 standard [7] were applied and the observations made, in both methods, satisfy the statistical test, are within the acceptable limit and considered approved.

In the verification of the horizontal and vertical limb of the total station, the Horizontal and Zenithal Angle Calculation Module of the AstGeoTop software [13] was used, using the data observed from the implanted structure composed of the points LG1 (17 targets with 2 sets) and LG2 (20 targets with 2 sets) as station points and irradiated to the points of interest (Figure 6 and Figure 7).

For the horizontal limb, the discrepancy of the horizontal angles registered a standard deviation of 15.16" and 7.18", and for the angular accuracy classification a standard deviation of 5.7" and 3.1", respectively. In the vertical limb, the discrepancy of the vertical angles obtained a standard deviation of 5.43" and 7.15", and for the angular accuracy classification a standard deviation of 3.4" and 3.8", respectively.

It was expected to achieve an angular accuracy close to ±2", since this is the accuracy of the instrument used. There are numerous justifications for not reaching the accuracy informed by the manufacturer, one of them is related to the fact that the automation of the robotic total station was not used in the search and collimation of the prism. However, the angular uncertainty reached is in accordance with NBR 13133 [12] with the average angular classification. In view of the results obtained, it is considered that both instruments are suitable to be used in 3D surveys of surfaces and built structures. For future work, it is recommended to automate the robotic total station for prism search and collimation at the observed points.

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